is now trying to locate funds, a site, and a chief.6/ Industry sources report that Sematech has commitments to join from semiconductor producers representing 80 percent of U.S. production.7/

EVALUATING THE PROPOSAL

Despite the preliminary status of Sematech's planning, enough of the major elements--purpose, program, and funding--is known to evaluate their potential contribution. This section does so, focusing on the following questions:

- Does Sematech address the right problems in the U.S. semiconductor industry?
- Does Sematech address the industry's problems in a way that also pursues national interests? and
- What risks does Sematech pose?

Does Sematech Address the Industry's Problems?

As noted in Chapter II, the weakness of the semiconductor industry lies in manufacturing technology generally, rather than in the sophistication of U.S.-made devices. But most R&D now carried out by semiconductor companies is in device design, not manufacturing technology.

Industry sources suggest that of the $2.0 billion spent by semiconductor companies for research, between 10 percent and 15 percent (or $200 million to $300 million) is for manufacturing R&D. Makers of semiconductor manufacturing equipment spend another $500 million.8/ The focus in Sematech on generic manufacturing

6. The SIA board is serving as a temporary Sematech Board, and the SRC staff is serving as temporary Sematech staff.

7. See Robert Henkel, "FYI," *Electronics*, August 6, 1987, p. 8.

8. Presentation on Sematech by Larry Sumney to the Workshop on DOE National Laboratories and the Semiconductor Industry, May 26, 1987.

equipment and technique would bring new resources to bear on an acknowledged weakness that current research efforts do not adequately address. The $250 million spent by Sematech would increase spending for research on commercial semiconductor manufacturing in the United States by about one-third--a sizable increase.9/

Sematech has good prospects for developing new manufacturing technologies. Given the attention it commands among industry leaders and the industry's financial commitments to it, Sematech will probably secure a highly qualified staff, and its results will be incorporated rapidly into actual production. But while Sematech will probably improve U.S. semiconductor manufacturing technology and may keep the semiconductor industry from falling further behind, it probably will not be able to restore the U.S. share of the world market to the levels enjoyed in the 1970s for several reasons. First, the semiconductor producers in Japan have substantial R&D programs and will continue to improve their manufacturing technology. Second, part of the success of Japanese semiconductor firms has come as a result of the success of Japanese producers of electronic equipment, and Sematech is not likely to reverse these gains. Finally, new producers from other countries will enter the semiconductor market, further eroding future U.S. market share.

Does Sematech Address National Interests?

Sematech addresses the three areas of federal interest outlined in Chapter III--national security, spillovers within the industry, and spillovers to the economy--though not to the same degree. Its greatest potential benefits will most likely accrue to the semiconductor industry; the contribution to national security, however, is unlikely to be substantial in the near term.

Spillovers and Learning. The major federal interest in the semiconductor industry concerns spillovers from research, both in the industry itself and the economy in general. These interests are likely

9. While some federal semiconductor R&D may be devoted to manufacturing technology, much of it--research on gallium arsenide manufacturing technology, for example--is commercially irrelevant in the short term.

to be fulfilled in some manner. Because of Sematech's plans for involving producers of manufacturing equipment, the resulting technological advances will probably be incorporated into the next generation of such equipment, benefiting all semiconductor producers. Improved manufacturing technology could in turn lower the costs of making products that use semiconductors--such as computers, robotics, communications equipment, and other electronic equipment--and finally result in lower prices to consumers.

Given the difference between societal and private benefits, as outlined in the previous chapter, the benefit to the United States as a whole could far outweigh either the federal or the private investment in Sematech R&D. Furthermore, the interest Sematech has already generated in the technical community indicates that the consortium is likely to stimulate the expected benefits to the scientific and engineering communities.

An important source of confidence in Sematech's prospects lies in its decision to concentrate on manufacturing technology. As discussed above, individual semiconductor firms do substantial amounts of research--far more than the national manufacturing average, even during periods of industrywide financial losses. But the bulk of this work concerns product design rather than manufacturing equipment or processes. Many economists believe that research on manufacturing process is underfunded, given its potential return to society.10/ The counterargument to this position, however, has generally been that one industry's process is another's product, and that improvements in product design in an input-supplying industry become improvements in process elsewhere.

This argument, however, is less persuasive in the semiconductor industry because of the disparate sizes of semiconductor firms and SME manufacturers. As noted above, U.S. SME firms are much smaller and compete against more firms than do their Japanese counterparts. Thus, the level of research in the SME industry may be out of balance with the level of research on the design of semiconductors.

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10. See, for example, Harvey Brooks and Bruce Guile, eds., *Technology and Global Industry: Companies and Nations in the World Economy* (Washington, D.C.: National Academy Press, 1987).

National Security. Improving semiconductor manufacturing technology may not reduce U.S. military dependence on foreign suppliers for specific devices. Nor can Sematech guarantee that U.S. producers of semiconductors will find filling U.S. military needs a profitable activity, especially given the bureaucratic and technological requirements that accompany defense contracts. Sematech may, however, increase the domestic availability of any given technology. Its greatest contribution to national security may lie in maintaining the vitality of the U.S. industrial base. Nonetheless, while any direct military benefits from Sematech would appear to be long-term and incidental, the lower costs resulting from improved manufacturing technology would benefit DoD as well as all other consumers of semiconductors.

What Are the Risks?

An effort such as Sematech inevitably poses a range of risks. One of these, of course, is the conventional scientific risk experienced in all such projects--that research will be fruitless. But this risk will be no greater for Sematech than for any other comparable research project. In particular, there is no reason to believe that it will experience greater risk on this score than would a project undertaken by one firm, rather than a consortium.

But Sematech's special characteristics raise a series of other issues, including:

- Whether Sematech's results would be disseminated to best national advantage;
- Whether Sematech's consortium design would become a precursor to a collusive arrangement;
- Whether Sematech would unduly centralize the nation's research agenda in semiconductors; and
- Whether both the private and public participants can succeed in the new institutional roles imagined for them in the Sematech proposal.

Dissemination of Results. Sematech's agenda is a promising one because it will investigate an area where the incentives to individual firms are limited but national gains could be great. Sematech's contribution, therefore, will be the greatest insofar as its results are quickly disseminated to domestic producers but still held within the national community.

The dissemination of Sematech's results to domestic producers is largely assured. The movement of engineers and scientists among firms and the general availability of new semiconductor manufacturing equipment should allow new manufacturing techniques to spread throughout the economy.

But the results of Sematech are also likely to spread abroad, thus defeating the purpose of the enterprise. To some extent this spread is inevitable, if less rapid, through the same media as domestic dissemination--personnel movements, research journals, word-of-mouth, equipment design, and the like. Foreign dissemination, moreover, can also take place through the activities of U.S. capital-affiliated firms that are members of the Sematech consortium. Specifically, the U.S. firms may use Sematech products and results in their foreign production sites; many such firms already operate production facilities in Japan, elsewhere in the Asian rim, and in other developing countries.11/

The fact that U.S. firms operate such facilities is not necessarily a loss for the U.S. economy. If some stages of production--such as low-wage assembly--relocate abroad while the engineering, skilled-production, scientific, and research work that accompanies it remains in the United States, then the gains imagined from Sematech may yet be obtained while still realizing lower production costs for many devices consumed here.12/ But production facilities inevitably incorporate advances in engineering and science, even if these functions remain in the firms' U.S. headquarters. In some nations, a transfer of technology may be a precondition for allowing foreign companies to locate a facility there. Thus, whether Sematech's

11. Most semiconductor devices imported into the United States are manufactured by U.S. capital-affiliated firms, not foreign firms (Department of Commerce, *U.S. Industrial Outlook, 1987* (1987), p. 32-4.

12. Relocating production facilities, however, entails important adjustment costs for displaced U.S. workers.

products and advances will be sent abroad by U.S. firms is as much an issue as whether they will be appropriated by foreign ones.13/

The Prospects for Collusion. An industrywide arrangement such as Sematech raises the prospect of collusion among members of the consortium to restrain trade.14/ For example, not allowing non-member firms to have access to the results could keep them from entering or expanding within the semiconductor industry. The existing plans for Sematech, however, would make research advances available to outside firms after a suitable period if a royalty is paid. Thus, Sematech members hope to gain a head start in familiarizing themselves with its research products rather than to achieve a long-term monopoly. Nonetheless, the conditions for dissemination of Sematech's research results are an important determinant of its effects on competition and are discussed in greater detail below.

An additional concern is that Sematech could become a springboard for collusive standard-setting by its member firms--for example, using a new generation of technological improvements to build semiconductors or manufacturing equipment with proprietary technology so as to make them incompatible with other, existing equipment. Standard-setting of this type is already a major advantage of the U.S. industry because of the near-ubiquitous need to be compatible with U.S. software. Yet attempts to redefine the standards of the industry could be self-defeating. In the 1960s, for example, the French government tried to enter the computer industry as a matter of national policy and promoted a "Plan Calcul" computer system that was not compatible with the then-dominant IBM

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13. To the extent that labor costs are higher in the United States than elsewhere, increases in the productivity of labor would lower U.S. manufacturing costs. Thus, the advantage to relocating abroad might diminish, and U.S. firms may expand their domestic production facilities instead.

14. Because the consortium plan has been modified to eliminate commercial production, proponents of Sematech argue that the consortium would be covered by the 1984 National Cooperative Research Act and thus would not need a special Congressional antitrust exemption. CBO's analysis does not discuss this act or its implications for Sematech.

design.15/ The effort was a catastrophic failure, and contemporary efforts to change standards might also fail.

Diversification of the Research Agenda. Sematech requires some measure of centralization in its research agenda. Through its collective efforts, semiconductor and SME producers will be agreeing on a common research program. The portfolio of projects selected will therefore be less diverse than if member firms had taken equivalent amounts of resources and established their own research agendas.

Centralization, of course, allows companies to avoid the waste of resources that occurs when individual research programs are duplicated. Moreover, it is unlikely that the member firms would ever individually devote the same level of resources to Sematech tasks, because of their inability to appropriate the full benefits of the research (as discussed in Chapter III). Thus, it is likely that Sematech will increase the absolute amount of research on SME technology, although some of this increase may be financed by firms doing less research on product design.16/

Yet Sematech could "guess wrong" in selecting a research agenda and in so doing be leapfrogged by foreign producers or pursue a path that leads to a technological cul-de-sac. Comparable criticisms have been made of the federal program that directed the nation's commercial reactors toward light-water technology instead of such alternatives as the high-temperature gas reactor--a direction taken largely, it is claimed, because small-scale versions of the light-water technology were already used on U.S. submarines.

Sematech's immediate emphasis on commercial technologies raises a comparable prospect; "horizon" technologies such as the use of gallium arsenide or X-ray lithography are being deferred in

15. William James Adams and Christian Stouffaes, eds., *French Industrial Policy* (Washington, D.C.: Brookings Institution, 1986).

16. Many economic studies suggest that increasing federal R&D spending in one area of research also raises private R&D in that area. See, for example, Kenneth Flamm, *Targeting the Computer: Government Support and International Competition* (Washington, D.C.: Brookings Institution, 1987), p. 184.

Sematech's plans. Other federal programs, however, fund research into activities that are not part of Sematech's research agenda.

Will the Institutional Arrangements Work? Sematech involves two relatively new institutional forms for U.S. economic policy--a research consortium of firms within an industry, and a public/private partnership with government a largely silent partner. Whether the groups involved can succeed in these new roles is unclear.

While the proposed consortium mimics the highly successful Japanese VLSI program, track records for similar U.S. consortia are short and mixed, depending on the criteria used. Many research and development ventures have been created since passage of the National Cooperative Research Act of 1984; 59 cooperatives have registered with the Department of Justice since January 1985.17/ They range from two-partner ventures focused on a single problem to corporations with many members and a long-range agenda.

Of these cooperatives, the experiences of the Microelectronics and Computer Technology Corporation (MCC) and the Semiconductor Research Corporation (SRC) are relevant to the proposed semiconductor consortium. While these two more modest joint efforts have proved successful, the industry has had a hard time cooperating in other major efforts. In 1981 and 1982, in response to the first major market gains by Japan, the U.S. semiconductor industry designed Operation Leapfrog with some of the same goals as Sematech. That effort foundered during the semiconductor boom of 1983-1984. This experience raises the question of whether Sematech will last in good times--for example, if U.S. producers are helped by a depreciation of the dollar--as well as bad.

A separate issue is whether any one company will have the incentive to send its best prospects--either labor or technology--to the consortium, or if Sematech will lack the discipline that a team organized by a single firm might have. The experience of the MCC suggests that a dynamic cooperative can hire researchers of better quality than can individual companies. The long-term focus of the

17. Department of Commerce, Office of Productivity, Technology, and Innovation, "Cooperative R&D in Industrial Competitiveness" (unpublished mimeo, March 16, 1987).

research itself and the size of the research groups, not the product or process applications, attract researchers. MCC has been able to hire about 20 percent of its staff researchers from universities and government laboratories.18/

Industry consolidations, mergers, and divestitures can also threaten a cooperative's long-term planning and viability. MCC had three members withdraw in 1986; only two have been replaced. Three other members have given notice that they will withdraw at the end of 1987. Most of these withdrawals resulted from mergers or divestitures in the industry, not from dissatisfaction with the work of the cooperative.19/ The exodus of member firms could destabilize the cooperative, however. If new members are not found, either remaining members will have to increase their support of research projects or the research agenda will have to be scaled back. Even after these departures, however, MCC membership remains at 17 companies, or 6 members more than they started out with.

Some of these cooperatives already have made breakthroughs in research and have disseminated their findings. MCC began delivering results to its members in the spring of 1985--earlier than the members had expected--through informal technology transfers and in laboratory sessions or seminars to brief sponsors on current research.20/ Because MCC's work is proprietary, full details and evaluations of the information conveyed are not available. One indication of MCC's success, however, is that some member companies--having seen the quality of MCC's results--have joined other research programs. And, an MCC member recently released the first product incorporating MCC-developed technology, an advanced design system for integrated circuits. A schedule has been set up for delivering additional research results to member companies in the near future.21/

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18. Merton Peck, "Joint R&D: The Case of the Microelectronics and Computer Technology Corporation," *Research Policy* (October 1986), pp. 219-231.

19. Lloyd Schwartz, "MCC Chief Hits Myths' of Cooperation Lack," *Electronic News*, July 20, 1987, p. 22.

20. Dr. Grant Dove, Statement before the Technology Policy Task Force of the House Committee on Science, Space, and Technology, July 15, 1987.

21. J. Robert Linebeck, "It's Time for MCC to Fish or Cut Bait," *Electronics*, June 25, 1987, pp. 32-33. Also see companion articles for further details.

Another issue concerns the role of the federal government, which has had little experience with this type of cooperative arrangement. Although it funds applied research with commercial value through such agencies as the National Aeronautics and Space Administration, the National Institutes of Health, and the National Science Foundation's Engineering Research Centers, the government itself is the director of the research agenda in these situations (with industry in a consultative role), rather than a "silent partner" as it would be in Sematech. Moreover, the issue of the social benefits associated with an industry's competitiveness is not the rationale behind these other efforts. To succeed, Sematech will require an agenda that meets the industry's needs. The government's role in creating such an agenda in this case is a consultative one. Sematech's prospects will depend to a great extent on the willingness of the government to take a cooperative and, in many respects, passive role in the consortium, once Sematech's basic policies have been set.

POLICY DESIGN ISSUES

Many details of the Sematech proposal remain to be determined. Yet enough is known to identify issues raised by Sematech's design that are of broad policy concern. Three of these issues are discussed in this section:

- The relationship between the dissemination of the results and the benefits of the program;
- The precedent established by Sematech in trade and adjustment policy; and
- The choice of federal agency that will manage Sematech.

Royalty Policy

The royalties that Sematech demands to license the use of its research results will help determine the rate at which these results are disseminated. As discussed above, the national benefits resulting from Sematech are furthered when these results flow within the national economy but not outside it. One way to control dissemination would be to adopt a licensing policy that charges progressively higher prices, with the lowest price charged to U.S. nonmember firms with U.S. production locations, the middle price to U.S. firms seeking to apply results in foreign production locations, and the highest price (or outright prohibition) to foreign competitors. Restricting access of non-U.S. firms to Sematech's results, however, would contradict the principle of open trade in services that the United States seeks to incorporate into the General Agreement on Tariffs and Trade (GATT). Furthermore, it would be extremely difficult to prohibit either U.S. or foreign firms that used Sematech's techniques in their U.S. locations from transferring them to foreign sites. Similarly, SME manufacturers who incorporate Sematech's innovations into their equipment would have to be restrained from exporting that equipment under such a policy. But these exports provide SME firms with revenues that fund further research and development and, therefore, contribute greatly to the vitality of the industry. And, as discussed earlier, scientific findings inevitably spread to all users through a variety of avenues. Thus, a pricing scheme for royalties that differentiates among classes of users may offer the best prospect for managing the dissemination of Sematech's research results.

Relying on royalties to control dissemination, however, does not obviate the need to have a long-term policy in mind when addressing the issues created by the foreign production sites of U.S. firms or the U.S. production sites of foreign firms. Attempting to discourage foreign firms from locating in the United States would deny the economy employment and the on-the-job training of skilled workers and engineers that occurs at production facilities. The level of access these firms are given to Sematech's results therefore should be related to the value of these benefits. Yet it would be virtually impossible to enforce an arrangement allowing firms to use a technique in a U.S. plant but not a foreign one. The federal representatives to Sematech may want to seek some general agreement on this issue as part of a larger understanding regarding the government's participation in Sematech and its policies toward the semiconductor industry in general.

Protection

Federal participation in Sematech, which is aimed at improving the prospects of a specific group of industries, raises the issue of protection--the most common form of federal assistance to industry. A previous CBO report discussed the generally-perceived failure of protectionist measures such as tariffs and quotas in assisting the industries to which they were applied.22/ That analysis identified two concerns: that protection did not address the sources of cost disadvantages in U.S. industries, and that it did not provide firms in those industries with incentives to modernize. Sematech, in contrast, would address a specific source of cost disadvantage in U.S. production and, if it succeeds in introducing a new set of manufacturing technologies into the industry, should increase the incentives for firms to invest. It therefore has many of the characteristics of a viable alternative to trade restraints.

The problem posed by Sematech with regard to protection is not the program itself but the precedent that it would set in this area. The persuasive arguments for Sematech do not concern whether or not the semiconductor industry is competitive, but what benefits (beyond simple output and employment) would accrue to the economy as a whole by having a viable semiconductor industry. Yet if the Congress determines to fund Sematech, it may soon have to decide whether other industries willing to form consortia and to impose a tax on themselves to advance their technological abilities also deserve similar federal support. Many industries may, in fact, merit such treatment, given the often-observed and pervasive weakness in U.S. manufacturing technology.23/

In many cases, promoting technology may be a better strategy than bearing the costs of adjustment in uncompetitive industries. This is not, however, an argument for making technology programs into a form of entitlement for uncompetitive industries (although the existence of tax credits for research and development is analogous to such an entitlement for profitable industries). Rather, this argument suggests that candidates for such programs be evaluated according to criteria like those used in this analysis and discussed in Chapter III.

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22. Congressional Budget Office, *Has Trade Protection Revitalized Domestic Industries?* (November 1986).

23. See, for example, Brooks and Guile, *Technology and Global Industry*.

The Choice of Program Manager

The federal role in the Sematech proposal is novel enough that it is not obvious where in the federal government it should be located. The House of Representatives has given most authority for Sematech to the Department of Defense for fiscal year 1988, although it also authorized the Department of Commerce to make grants to Sematech in the Trade and International Policy Reform Act of 1987 (H.R. 3). The Senate Armed Services Committee has reported a bill that would give Sematech a $100 million authorization through the Department of Defense for fiscal year 1988. Subsequently, the Senate included a provision in the Omnibus Trade and Competitiveness Act of 1987 (S.1420) that would establish an interagency coordinating committee to oversee federal participation in the program. A final version of these trade bills for vote by the House of Representatives and the Senate has not yet been agreed to in conference.

The Department of Defense, with a 40-year history of overseeing programs aimed at assisting semiconductor and computer technology, has the technical and operational expertise to handle a large program like Sematech. The fact that DoD's research arm, the Defense Advanced Research Projects Agency, supported the computer industry throughout the 1960s provides one reason for assuming that a stronger computer industry would benefit DoD as a consumer. Its Manufacturing Technology (ManTech) program assists firms in the defense industrial base in adopting advanced technologies. The Very-High-Speed Integrated Circuit (VHSIC) program is the latest of these programs. Appendix A details the approximately $300 million in semiconductor programs now managed by DoD. These programs reflect DoD's awareness of the role that a competitive industrial base plays in the nation's defense.

Most of these programs, however, have reflected DoD's intention to drive the technology of an emerging area in a direction more compatible with anticipated defense needs. This, rather than commercial success or a "response" to foreign challengers, was the intention of the VHSIC program.24/ This highly focused approach has been taken

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24. See National Research Council, Commission on Sociotechnical Systems, National Materials Advisory Board, *An Assessment of the Impact of the Department of Defense Very-High-Speed Integrated Circuit Program* (Washington, D.C.: National Academy Press, 1982).

with such technologies as the radiation hardening of chips (which allows them to survive nuclear war) and the use of gallium arsenide as a semiconducting material. Given this orientation, DoD has consistently managed these programs to achieve technological performance at the expense of cost. For example, high-speed gallium arsenide 16K SRAMs are planned as part of the Strategic Defense Initiative at a cost of $1,200 each in 1988; an existing fast commercial version is available for $20 or less.25/ It is not surprising that prototypes of new technological devices have these costs. But the purpose of Sematech is to develop cost-effective commercial technologies, not to pursue technologically demanding but commercially irrelevant directions.

A proposed alternative to DoD would be an interagency coordinating committee, chaired by the Department of Defense, and including the Department of Commerce, the Department of Energy and its National Laboratories, and the National Science Foundation. The committee would be advised by an Advisory Council on Federal Participation in Sematech that comprises industry, scientific, and defense representatives.

The advantage of such a committee is that it would bring together a wide range of interests within the federal government, allowing it to apply greater expertise and focus on broader, long-term interests. On the other hand, the committee would have to form itself rapidly to administer effectively the $100 million annual appropriation due Sematech. Moreover, current legislation pending in the Senate would give the committee a full-time staff of only seven people, forcing it to rely heavily on personnel who are detailed from the agencies represented on the committee. Given that there are few personnel available at the Department of Commerce to make decisions regarding a technological research agenda and that the work funded by the National Science Foundation is done by outside contractors, the bulk of these experts will come from the DoD and its attendant laboratories and from defense-related functions within the Department of Energy. This composition may lead to a defense-dominated view of the semiconductor industry in the committee's dealings with Sematech.

25. Presentation by Fung-Sun Fei to the Main Workshop on DOE National Laboratories and the Semiconductor Industry: Continuing the Joint Planning, at Sandia National Laboratory, Albuquerque, New Mexico, May 27, 1987.

APPENDIXES

APPENDIX A

FEDERAL SPENDING ON SEMICONDUCTOR R&D

Federal agencies will spend $400 million to $500 million on research into semiconductor materials, design, and manufacture in fiscal year 1987 (see Table A-1). Most of this money, however, is used to develop military and other noncommercial applications rather than to further the development of manufacturing technology that would benefit the industry as a whole. The federal agencies that conduct or support semiconductor R&D include the Department of Defense (DoD), the National Laboratories (NL) of the Department of Energy (DOE), the National Science Foundation (NSF), and the National Bureau of Standards.

The largest federal effort is DoD's development of radiation-hardened (rad-hard) integrated circuits, which represent only about 3 percent of chip sales and have only limited commercial applications. The other major focus of federal research is the use of materials other than silicon, most notably gallium arsenide (GaAs).

DEPARTMENT OF DEFENSE

The Department of Defense has two categories of semiconductor programs: R&D programs conducted by the branches of the armed services, and programs associated with the Office of the Secretary of Defense. Each service branch has a substantial ongoing program of semiconductor research, focusing on its specific needs. The Office of the Secretary of Defense (OSD) also a high level of semiconductor research. The largest of these programs is the Very-High-Speed Integrated Circuit (VHSIC) program, which focuses on the insertion of sophisticated integrated circuits (ICs) into weapons bought by DoD. The Strategic Defense Initiative Organization (SDIO) funds the development of both silicon and GaAs technology. The Defense Advanced Research Projects Agency (DARPA) supports a wide variety of semiconductor design and production efforts. The Manufacturing

TABLE A-1. FEDERAL SPENDING FOR SEMICONDUCTOR RESEARCH IN FISCAL YEAR 1987

Agency	Outlays
Department of Defense	
Office of the Secretary of Defense	
Very-High-Speed Integrated Circuits	122
Strategic Defense Initiative Organization	60
Defense Advanced Research Projects Agency	16
Manufacturing Technology	14
Microwave and Millimeter-Wave Monolithic Integrated Circuits	10
Defense Nuclear Agency	7
Armed Services	
U.S. Air Force	60
U.S. Navy	28
U.S. Army	25
Independent Research and Development	a/
Department of Energy	
National Laboratories	
Sandia	55 b/
Lawrence Berkeley	4
Brookhaven	2
Other	2 c/
Photovoltaic Research	15
National Science Foundation	30
National Bureau of Standards	4
Subtotal	454
Incremental R&D Tax Credit	75 d/
Total	529

SOURCE: Congressional Budget Office.

a. Cannot be estimated; see text.

b. Excludes work performed at Sandia but reimbursed by the Department of Defense.

c. Includes Oak Ridge, Lawrence Livermore, Ames, and Argonne.

d. Average of 50 and 100. See text for details.

Technology program (ManTech) spends a small amount on semiconductor manufacturing. The Microwave and Millimeter-Wave Monolithic Integrated Circuits (MIMIC) program is similar to VHSIC, but concentrates instead on telemetry circuits made from gallium arsenide, a faster alternative to silicon. The Defense Nuclear Agency (DNA) focuses on the development of rad-hard chips for use in nuclear weapons. Finally, the DoD reimburses federal contractors for a portion of their research costs under the Independent Research and Development (IR&D) program. Some IR&D funding has been going into semiconductor work.

Office of the Secretary of Defense

The Very-High-Speed Integrated Circuit Program. The VHSIC program was established in the late 1970s, after DoD had little success in interesting semiconductor firms in designing and manufacturing integrated circuits for military use. Semiconductor makers felt that military devices lagged in technical sophistication and had stringent radiation, temperature, and other environmental requirements that made them too expensive for the commercial market. The limited commercial spinoffs discouraged semiconductor firms from producing the integrated circuits needed by military planners despite the unit profits such chips might bring.

The VHSIC program was designed to ensure that sophisticated integrated circuits would be built for military use and that the military would actually use them. Thus, the program has devoted little funding to developing generic semiconductor technology or to improving semiconductor production equipment.1/ In fiscal year 1987, for example, less than half of the $122 million VHSIC expects to spend will be spent on semiconductor technology. The program has developed software for designing integrated circuits at a cost of $14.5 million. Another $46.8 million is being spent on technology development of both ICs and their use in prototypes. In line with the desire to increase DoD's use of advanced semiconductors, a large part

1. For instance, only a few million dollars was spent on photolithographic systems, and the original $5 million to develop a laser-powered wafer stepper was cut back to roughly $2 million. (Brian Santo, "New VHSIC Litho[graphic] Systems Readied for User Testing," *Electronic News*, March 9, 1987.)

of the funds has gone to systems development and insertion techniques. Some funds were spent on yield enhancement, but this effort tended to be applicable to specific devices and production lines.

VHSIC is in the process of winding down, after having achieved many of its goals. Under the program, the sophistication of chips designed for military use has grown--although not as rapidly as that of commercial chips--and the military has begun to design products and systems around these chips.

Strategic Defense Initiative Organization. The SDIO has two main research programs on semiconductor manufacturing in progress, totaling $61.3 million in fiscal year 1987. The major project, costing $41.5 million, consists of a series of GaAs pilot-production lines to build high-density devices for eventual use in a space-based real-time computer. The proposed devices, which are more complex than most commercially available GaAs devices, include a 16,000-bit static random access memory (SRAM) and some gate arrays. The program is proving the manufacturing technology by increasing the number of usable devices that emerge from the production lines. Other than supercomputers, civilian uses for such devices include heterojunction optoelectronics (light-driven computer interconnects). SDIO's other research project is on semiconductor manufacturing, costing $19.8 million in fiscal year 1987, which deals with radiation hardening of silicon. Unlike GaAs, silicon is very easily affected by radiation like that which exists in space or would be produced in nuclear war. Weapons based in space or intended for use in nuclear warfare therefore require rad-hard chips.

Defence Advanced Research Projects Agency. Current estimates suggest that DARPA will spend between $16 million and $17 million on research related to semiconductor manufacturing in fiscal year 1987. Much of the work they fund has both commercial and military applications. Universities perform 40 percent of this research.

One aspect of DARPA research that has had significant commercial payoff has been the modeling of silicon processes. Using a computer program developed at Stanford University, a semiconductor manufacturer can present the design of an integrated circuit, and the computer program will tell the manufacturer how to sequence the processing steps. The third and fourth editions of this program have been widely used in industry. DARPA is now turning the updating of this program over to the Semiconductor Research Corporation, an industry research consortium, and is focusing its attention on producing the same type of program for GaAs devices.

In addition, DARPA is funding research in advanced materials, including ceramics and metallurgy, and is also sponsoring research on advanced processing techniques using focused ion beams and lasers to enable semiconductor manufacturers to work on a small part of the device at a time.

Manufacturing Technology. DoD gives its contractors research funds to enhance their production technology. The Manufacturing Technology (ManTech) program is spending an estimated $14.3 million on semiconductor manufacturing technology in fiscal year 1987. Radiation-hardened devices account for $7.3 million; solid-state microwave systems for $4.6 million; and mercury-cadmium-telluride (HgCdTe) arrays for $2.4 million.2/

Microwave and Millimeter-Wave Monolithic Integrated Circuits. The MIMIC program focuses on producing microwave and millimeter-wave sensors for military systems, such as satellites, radars, and guided munitions. Current projections suggest that MIMIC will cost $10.3 million in fiscal year 1987 and over $500 million through 1992. The DoD accounts for a major share of the microwave and millimeter-wave integrated circuits. However, these devices are too expensive to incorporate widely into weapons systems. Because of the stringent frequency, radiation, and environmental requirements, MIMIC will primarily use gallium arsenide technology.

Defense Nuclear Agency. As the agency within DoD responsible for nuclear weapons, the DNA is charged with helping to ensure the survivability of the weapons systems the department purchases. Agency researchers study, for example, the effects of atomic blasts (electromagnetic pulse) on electronic components. DNA is projected to spend $6.6 million on semiconductor research, all of which is devoted to radiation hardening.

2. HgCdTe is a semiconducting material, one of the so-called III-V compounds that have properties of interest to the military in specialized applications, but only limited near-term commercial use.

Armed Services

U.S. Air Force. Current projections suggest that in fiscal year 1987, the U.S. Air Force will spend $59.7 million on semiconductor research, including research on materials and devices. The largest single program ($16.8 million) is developing GaAs technology. The next largest program ($7.3 million) concentrates on electro-optics such as lasers, detectors, and optical computing. Other research efforts include $6.8 million for microwave circuitry; $6.4 million for developing silicon chips, including radiation hardening and three-dimensional work; and $6 million to enhance the yield of an advanced data/signal processor. In all, the manufacturing initiatives account for $15.1 million, slightly more than half of which is for silicon.

U.S. Navy. In fiscal year 1987, the Navy's semiconductor research will total an estimated $27.5 million, including research on materials and devices. Much of the research does not involve silicon, which is the mainstay of the commercial market. Of the total, research on materials and electronic structures for semiconductors accounts for $15.9 million. (In this context, the Navy is experimenting with superconducting solid-state devices.) The Navy is spending another $5.4 million on advanced analog devices, $4.5 million on radiation-hardened digital devices, and $1.1 million on solid-state infrared sensors. The rest of the money is being used for control components.

U. S. Army. The U.S. Army is spending $24.8 million in 1987 on semiconductor research. The work includes R&D on radiation hardening, substrates, and materials. The Army is also performing research on ultra-high-speed integration. Other R&D programs focus on reliability and on upgrading obsolete semiconductors.

Independent Research and Development

The IR&D program allows defense contractors to add an overhead charge of between 3.5 percent and 4.0 percent to their sales to the government. The overhead charge, usually in the form of negotiated reimbursement for costs incurred, is to be spent on projects with potential federal relevance. A portion of the $3.5 billion spent by DoD in reimbursing federal contractors under the IR&D program is being spent on semiconductor research. Some defense contractors, for example, may be using their IR&D funds to break into GaAs technology. Because of the structure of the IR&D program and the